BBC RD 1982/7

RESEARCH DEPARTMENT REPORT

Colour separation overlay and its relation to digital video sampling

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June, 1982

BBC RD 1982/7
621.391.837.43

COLOUR SEPARATION OVERLAY AND ITS RELATION TO DIGITAL VIDEO SAMPLING

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Summary

Current techniques for Colour Separation Overlay (CSO) are briefly described. The influence of CSO techniques on the formulation of standards for digital video sampling parameters is discussed and experiments are described which investigated the effects on CSO pictures of filtering and sampling the foreground picture signals. The conclusions are that a chrominance bandwidth of at least 3 MHz, (implying a sampling frequency of at least 6 MHz) is needed for satisfactory CSO whereas luminance sampling frequency need not be constrained by CSO considerations. Hence a YUV sampling frequency standard of 13.5, 6.75, 6.75 MHz appears to be commensurate with good-quality CSO.

This work was carried out as part of investigations by EBU members into digital video sampling parameters. Its substance was reported to the EBU in November 1980 and formed part of the evidence on which the 13.5:6.75:6.75 system was chosen for digital video sampling.

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

June, 1982

(PH-228)

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PH228

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1. Introduction

Overlay techniques have long been used in television to combine pictures for special effects or to place artists in a scene without building expensive scenery.[1] When colour operation started, it became possible to use a proposal made in Ref 1 for making an overlay key discriminating foreground from background by colour.[2] Artists appear against a uniform coloured background (usually blue) and a new background is electronically keyed in where the blue background is detected. Such systems are known as Colour Separation Overlay (CSO) in the BBC. Other terms used are "chroma-key", or, more recently, "colour matting", reflecting the introduction of techniques used in the film industry.

Recently, CSO has come into prominence in discussions on digital video sampling parameters. It is generally agreed that digital video signals in studios should consist of separate components, luminance (Y) and two chrominance signals, (U and V).* CSO has been found to impose the most stringent demands on the choice of chrominance sampling parameters. It was principally because of its poor performance with CSO that a 12:4:4 proposal (luminance sampled at 12 MHz and U and V each at 4 MHz) was rejected in the EBU. If the chrominance sampling frequency is too low, CSO pictures may be soft or affected by aliasing distortions giving a stepped appearance on keyed edges. In a sampled system the signal frequency must be restricted to half the sampling frequency to prevent aliasing. Moderate aliasing in chrominance signals is not usually noticeable, but the CSO process transfers the aliasing from the chrominance, via the key signal, into the luminance where it is more visible. The aliasing may be prevented by severe lowpass filtering before sampling, but this causes overshoots and rather soft pictures. The only solution is to raise the chrominance sampling frequency to allow a wider bandwidth free of aliasing. Several experiments investigating the minimum bandwidth and sampling frequency needed for CSO have been carried out; the BBC's experiments are described in this Report.

It has also been suggested[3] that problems with CSO might affect the sampling frequency used for luminance in a digital system. This is because conventional CSO involves nonlinear processing which can generate frequency components outside the video bandwidth, and thus aliasing distortions. A

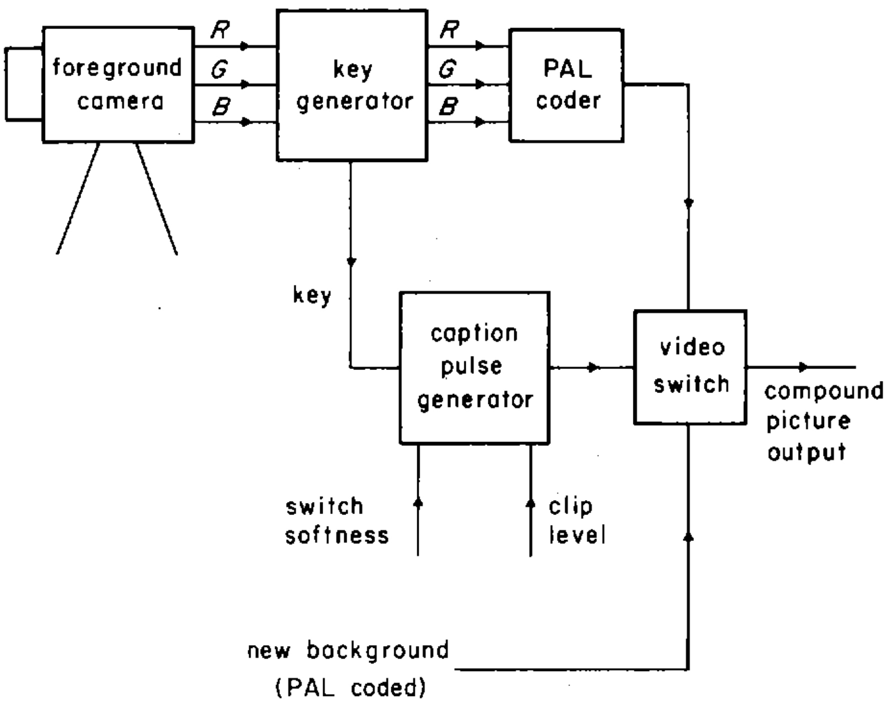

Fig 1—Block diagram of basic analogue CSO

* Strictly speaking, the terms U and V refer to the chrominance modulating signals in the PAL system which are related to the colour diffesence signals $B - Y$ and $R - Y$ by the equations $E'_U = 0.493$ $(E'_B - E'_Y)$ and $E'_V = 0.877\,(E'_R - E'_Y)$. But the terms U and V are often used to denote the colour difference signals themselves.

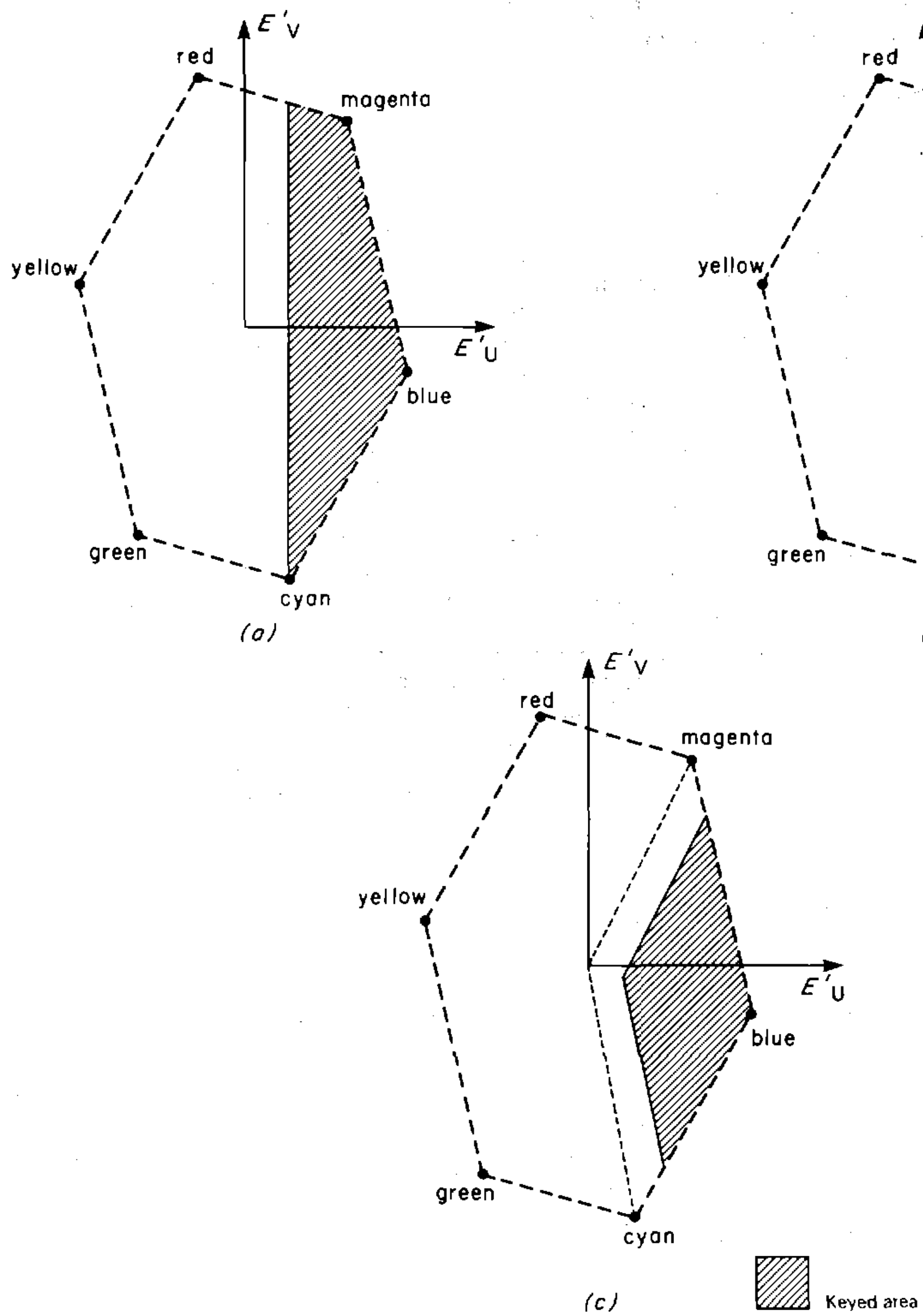

Fig. 2—Effect of different forms of key generation: (a) B–Y Key; (b) B–M Key; (c) Exclusive Blue

rearrangement of the conventional CSO process is described which avoids this aliasing.

2. Present analogue CSO*

A block diagram of a simple analogue CSO is shown in Fig. 1. The key generator takes *RGB* signals from the foreground camera and generates a key signal from them. The key signal is processed by the caption pulse generator, with adjustment of gain to control the hardness or softness of the switch and adjustment of offset to control the switching level. The key signal then controls mixing of the foreground and background signals (in PAL coded form) in a video switch unit. This

* Only a brief description is given here; a full review of the principles and use of CSO is given in refs (4) and (5).

unit consists of two voltage-controlled amplifiers operated in antiphase whose outputs are added together. Thus the so-called video switch does not in fact switch between foreground and background, but fades between them at a rate controlled by the slope of the key signal. This is the principle of the soft-edge switch.

In early equipments the key signal was the colour difference signal $E'_R - E'_Y$ (in the case of a blue background) where E' denotes a gamma-corrected signal. Later, the signal $E'_B - M$ was tried where $M = (E'_R + E'_G + E'_B)/3$. In the latest "exclusive key" equipments a simple nonlinear key generator is used where the key signal E_K is given for a blue background by

$$E_K = (E'_B - E'_R),\ E'_R > E'_G$$
$$E_K = (E'_B - E'_G),\ E'_G > E'_R$$

The effect of these different key generators is shown in Fig. 2. This Figure shows slices through *YUV* space (with luminance normal to the plane of the diagrams) such as would be seen on a vector-scope display. Some commercial equipments use a variable matrix so that the keying colour and the selectivity (the included angle of the segment in Fig. 2c) are continuously variable.[6]

The soft-edge switch gives a smooth transition between foreground and background without the spiky effect characteristic of earlier fast switches, but it can leave a pronounced blue fringe round foreground objects. The blue fringe is caused partly by filtration of blue light through hairy or coarse-textured edges of foreground objects and partly because some blue background comes through the soft-edge switch. The blue fringe can be eliminated by hue suppression, that is by limiting the foreground signal after key generation so that blue is less than red or green, whichever is greater. If the blue background were fully saturated it would thus be reduced to black. In practice, the background colour is neither fully saturated nor exactly on the blue axis, so it is reduced to a pale cyan or magenta. Fringe elimination modifies all foreground colours in the area shown in Fig. 3, moving them back to the line where blue equals red or green; this is generally felt to be a small penalty compared with the near elimination of the blue fringe.

The hue-suppressed foreground signal is still multiplied by the key signal, removing all detail in the area which was previously blue. Any imperfections in the blue background are thus removed, but the shadows cast by the foreground objects on the blue background are lost; these shadows may be needed if a realistic compound picture is wanted, rather than a special effect. Special measures, such as modulation of the new

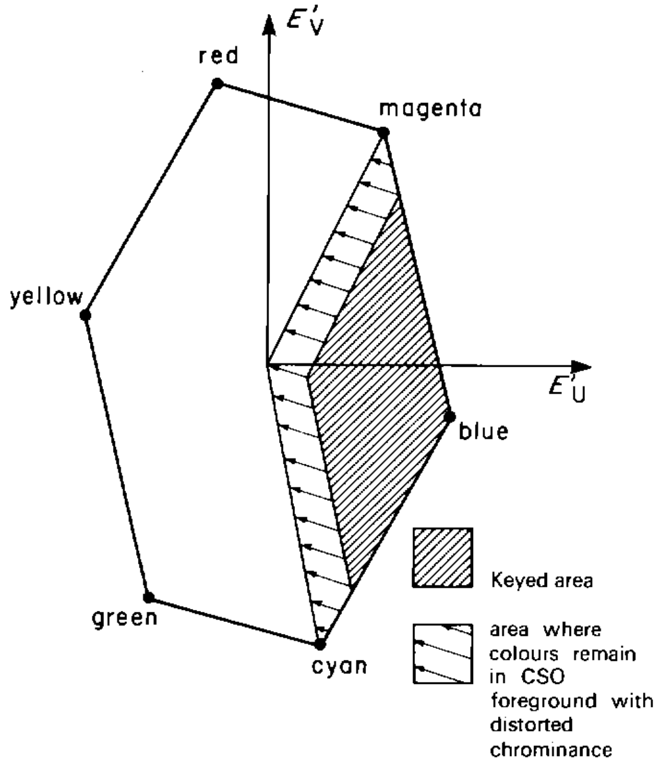

Fig. 3—Vector diagram showing effect of fringe elimination

background by foreground luminance, have to be taken to preserve shadows. Complex matting and clipping controls are needed to ensure that only wanted shadows are carried over into the final compound picture.

It is possible to preserve shadows using a simple rearrangement of standard equipment. This rearrangement gives improved rendering of transparent objects; it may be a convenient way of avoiding some problems of CSO in digital systems, as discussed in Section 3.

The hue-suppressed foreground signal (point A in Fig. 4) contains the foreground objects (including transparent or translucent ones such as glasses or smoke) along with their shadows. So if the background is simply added to the hue-suppressed foreground, the shadows will be preserved. The compound picture signal will then be somewhat "sat up" (offset positively), and will have a slight colour cast because the hue suppressor does not reduce the blue areas to a perfect grey (as pointed out above). In the arrangement shown in Fig. 4, this coloured sit is cancelled by subtracting a "reference background" signal from the new background. The "reference background" signal can be generated by a PAL coder with manually variable amounts of mixed blanking fed to each of its R.G.B inputs. The signal at point B in Fig. 4 is thus the new background, sat down and with a colour cast opposite to the foreground signal at point A. The signal at point C is this sat down

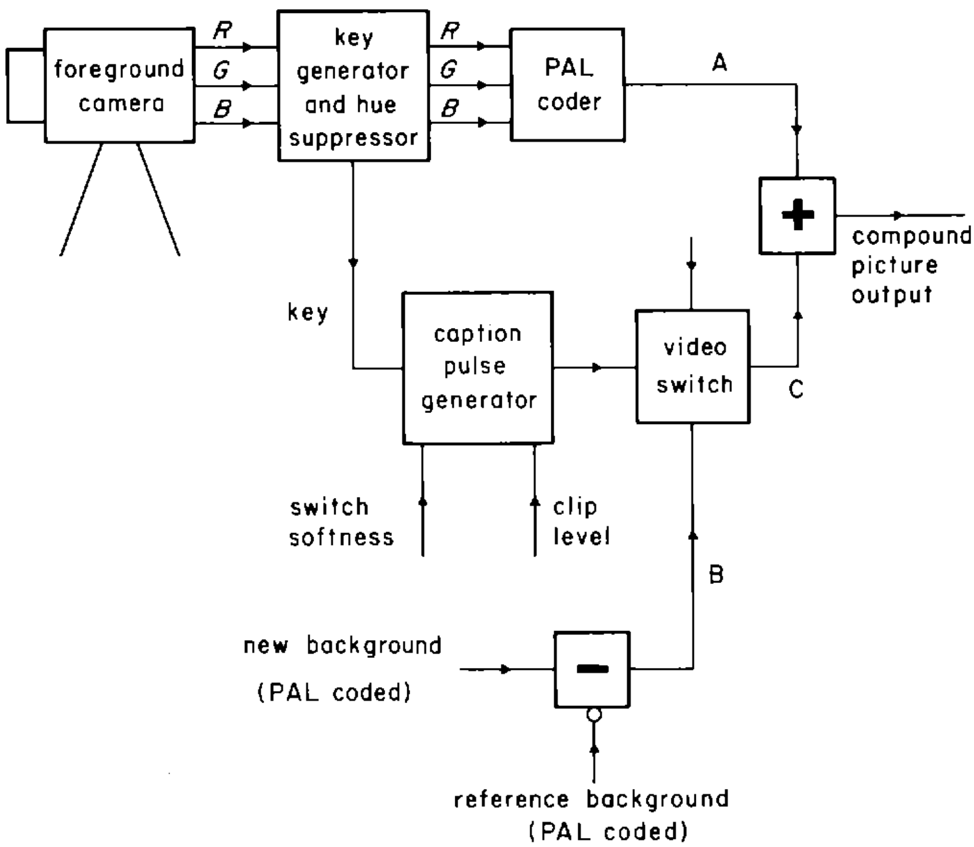

Fig. 4—Alternative arrangement for CSO

background signal, matted to black where there are opaque objects in the foreground signal.

This rearrangement (which was proposed for the work described in this Report by M. Weston) is not new: it has been used operationally in BBC Television as part of a versatile CSO equipment for the reproduction of shadows and transparent objects.* When used in the completely linear additive way described above, it has the disadvantage that all imperfections in the blue background are carried through to the compound picture. In practice, therefore, the background can be clipped in areas (defined by an electronic or hand-drawn matte) where shadow and transparency reproduction is not needed.

3. CSO and digital standards

3.1 Luminance sampling frequency

It has been suggested[3] that a digital CSO needs a luminance sampling frequency considerably above the Nyquist limit of twice the highest luminance frequency. The argument is that the foreground luminance signal is multiplied by the keying signal which is derived mainly from the foreground chrominance signals. The transitions of the luminance signal will therefore be correlated with the key signal. The spectrum of the luminance transitions may extend to 5.5 MHz; that of the key signal may extend to say 3 MHz. When two signals are multiplied, their spectra are convolved, so that the resulting spectrum may extend to 8.5 MHz which would need a sampling frequency of 17 MHz to support it. In practice, it is suggested, a sampling frequency of about 14 MHz would be sufficient, but a frequency much lower would give problems with aliasing.

There are several reasons for believing this aliasing effect to be insignificant in practice. The analogue television signal is sampled at a relatively low frequency in the vertical direction by the scanning structure, but aliasing from nonlinear processing such as CSO has not been noticed in the past. The problem has been investigated during work on digital signal-processing channels: in a gamma corrector, alias components can be generated in a similar way by the nonlinear processing, yet the resulting alias could be seen only on 100% amplitude sine wave electronically-generated test signals.[7,8]

* This equipment was devised by I. D. Chisholm and D. Jervis.

The problem disappears completely if the alternative arrangement described in Section 2 and shown in Fig. 4 is used. In this case the foreground signal is not multiplied by the key signal, so the aliasing never arises. The background is still multiplied by the key signal, but the transitions are not correlated so this multiplication is less likely to cause trouble.

3.2 Chrominance sampling frequency

Most proposals for digital video sampling standards have the chrominance signals sampled at half or one third the luminance sampling rate. This requires that the chrominance be lowpass filtered to half or one third the luminance bandwidth. This is allowable because sharp luminance transitions subjectively cover the loss of chrominance resolution caused by lowpass filtering. In the same way, aliasing in the chrominance signals – causing a stepped effect on edges – is subjectively masked by alias-free luminance transitions. Thus it appears possible to use a slightly lower chrominance sampling frequency than the Nyquist criterion would allow, or a lowpass filter with a slow roll-off to avoid ringing, because the aliasing, although present, is not noticed. However, in CSO the aliasing will be transferred to the key signal, which is formed from the chrominance signals, and thence to the luminance signal where it will be obvious. To avoid this aliasing effect the chrominance signals must be filtered to an even lower bandwidth which may cause ringing if the filter has a high rate of cut or may cause foreground objects to be poorly defined if the bandwidth of the chrominance signals is too low.

4. Experimental work*

Some experiments have been carried out to investigate the effects of filtering and sampling of chrominance signals. These experiments used an analogue CSO equipment preceded by digital filtering and subsampling of chominance signals. The digital processing was carried out in equipment built for EBU demonstrations of the 12:4:4 standard. The equipment converted analogue *RGB* signals to digital *RGB*, and then to digital *YUV*, all at 12 MHz. In the *YUV* domain, the chrominance signals could be filtered with one of two filter characteristics and their 12 MHz sampling frequency reduced to 4 MHz. The two filter characteristics were a sharp-cut filter flat to 1.7 MHz and −6dB at 2 MHz, and a gaussian filter also −6dB at 2 MHz. The two filter characteristics are shown in Fig. 5. When the chrominance signals were subsampled at 4 MHz interpolators were needed to bring the sampling rate back up to 12 MHz to suit the equipment. The interpolators contained a lowpass filter to remove the alias spectra centred on 4 MHz. The frequency characteristic of the interpolator filter and the residual alias spectra from the presampling filters are shown in Fig. 6.

The foreground signals were provided by a colour camera. The frequency response of the camera and its processing channels was investigated using a zone plate test pattern. All three

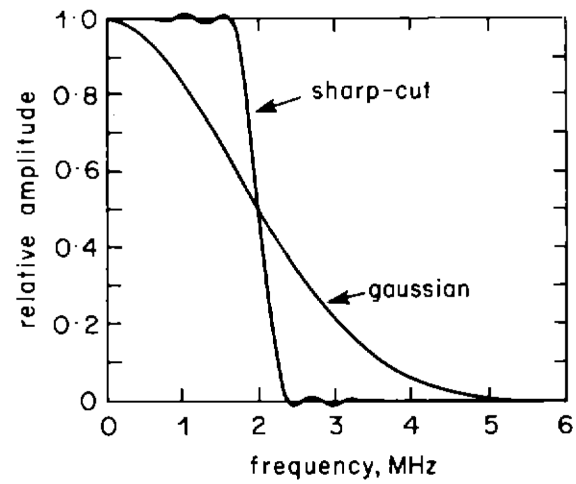

Fig. 5—Frequency responses of chrominance prefilters

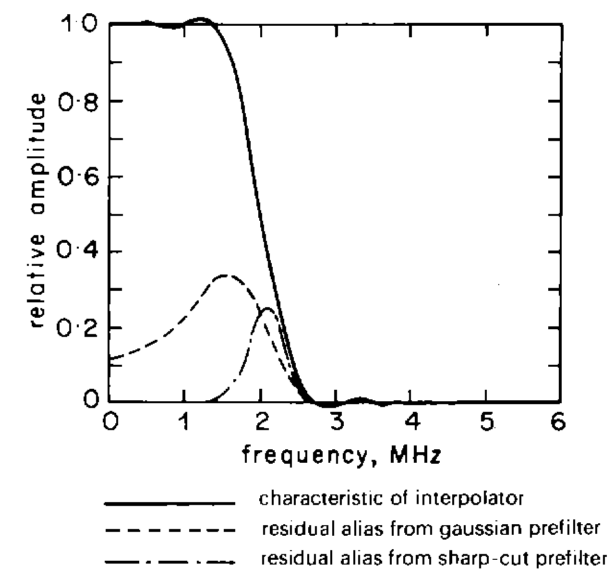

Fig. 6—Frequency response of interpolator, showing residual alias spectra

* This work was carried out by A. Oliphant and M. Weston.

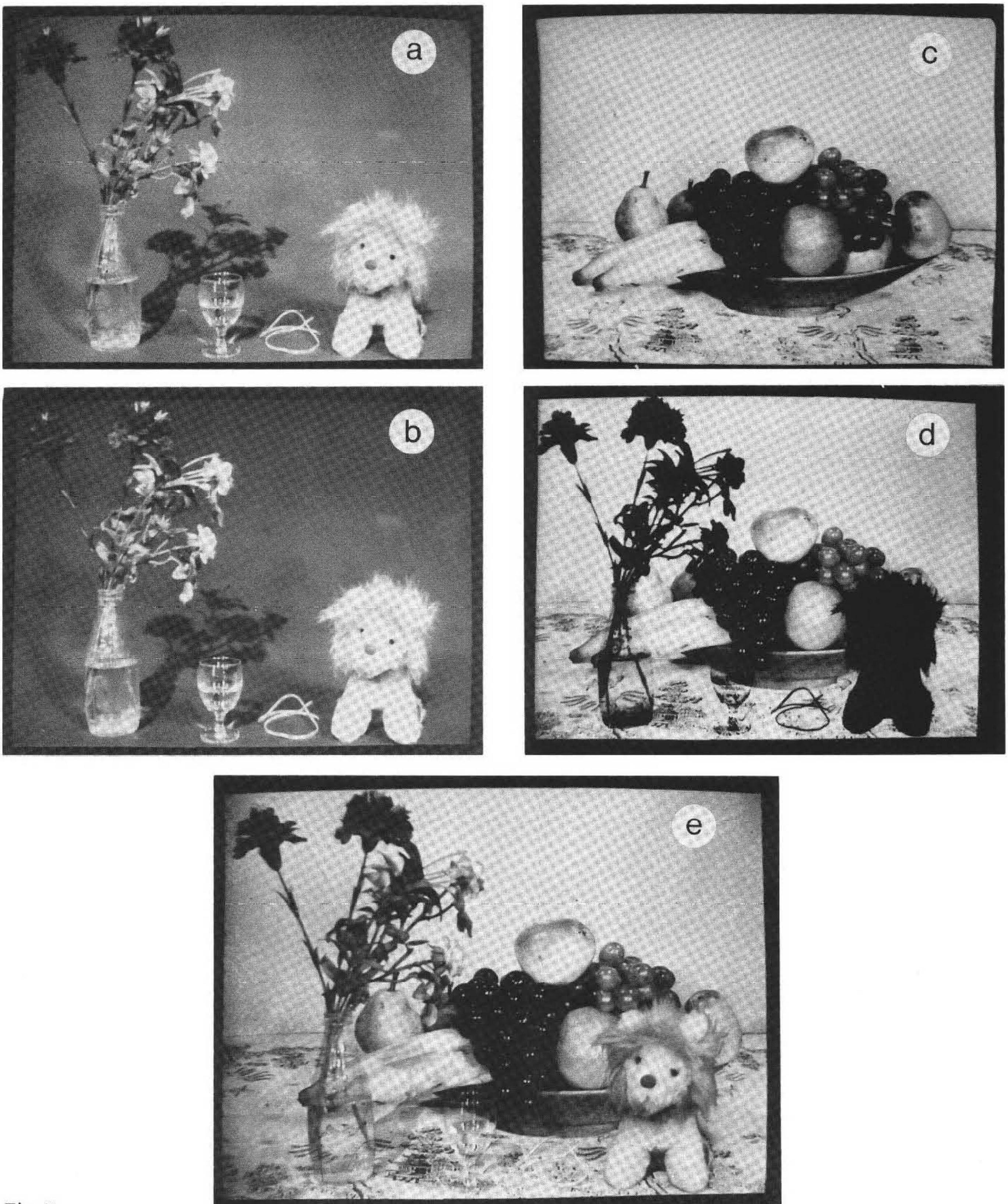

Fig. 7 -

Improved techniques for colour separation overlay (CSO) have been demonstrated at Research Department. Instead of the normal switching between the foreground and background pictures, the foreground (a) has the keying colour suppressed (b) and the background (c) is multiplied point-by-point by the intensity of the keying colour in the foreground to give a processed background (d). The intermediate pictures (b) and (d) are summed to give the output picture (e). Note that the transparency and the shadows of the bottle and glass are preserved.

Fig. 8—Effect of chrominance aliasing on CSO compound picture – visible as a stepped effect on flower stems

channels were about -2 dB at 4 MHz and $-5\frac{1}{2}$ dB at 5 MHz. The three channels were individually aperture-corrected rather than taking "contours out of green".

The foreground scene consisted of a group of objects on a table with a CSO blue baize cloth hanging down behind and pulled forward to cover the table top. The objects on the table were a milk bottle with a bunch of long-stemmed artificial flowers, a wineglass half full of water, a twist of fine white-covered equipment wire to give high-contrast fine detail and a small furry toy lion with a mane of long yellow hair. The background scene came from a flying spot slide scanner and consisted of a bowl of fruit on a table. The scene is shown in Fig. 7, which also shows the stages in the production of the compound picture as detailed in Section 2.

The analogue CSO equipment consisted of standard units connected as shown in Fig. 4. Some extra attenuation was used in the key signal path to give a very soft switch, as this produced the most realistic results.

Without subsampling the effect on the input camera picture of introducing either chrominance filter was small. The sharp-cut filter gave some ringing and the gaussian filter was slightly softer. Both filters gave acceptable CSO without subsampling, but the sharp-cut filter gave better definition of the stems and leaves of the artificial flowers. Neither filter gave results as good as unfiltered signals gave.

If the chrominance signals are not adequately filtered before being sub-sampled at 4 MHz, then aliasing will occur, as discussed in Section 3. Aliasing was expected to be particularly visible as a "stepping" effect on the near-vertical stems of the artificial flowers. CSO was expected to make chrominance aliasing more visible by transferring it via the key signal to the luminance signal. This proved to be correct: aliasing was almost invisible on the input camera pictures (it was not severe even with no presampling filter); but aliasing was always visible on the compound CSO picture. With the sharp-cut filter the aliasing was barely visible on a stationary picture, but it became more noticeable when the milk bottle and flowers were moved. The effects of aliasing are shown in Fig. 8.

In further tests, programmable digital transversal filters were used in place of the fixed filters. Two further filter designs were used, one -14 dB at 2 MHz (more suitable for 4 MHz sampling than either of the filters described above) and one -14 dB at 3 MHz, which might be suitable for sampling at 6 MHz. The narrower band filter gave marginally acceptable CSO, though foreground objects in the compound pictures were rather soft and some ringing could be seen. No aliasing effects from 4 MHz subsampling could be seen, even with moving pictures. This showed that 14 dB attenuation at half sampling frequency was sufficient in the chrominance channels.

When the second filter, -14 dB at 3 MHz, was used without subsampling, there was no difference in the compound CSO picture between the filtered and unfiltered conditions; they both gave satisfactory CSO.

The realism of compound CSO pictures is strongly dependent on the objects and lighting in the foreground scene. The objects chosen for the foreground in these experiments were thought to be fairly critical, but later work carried out during EBU demonstrations of various digital standards at the IBA Experimental and Development Department showed that more critical material could be chosen which could give different results. In particular, scenes with brightly coloured combs and scenes containing pieces of twisted coloured ribbon in the foreground showed increasing quality of CSO with increasing chrominance bandwidth until the chrominance bandwidth was equal to the luminance bandwidth. These tests were carried out using a special colour matting device which operated entirely on RGB colour separation signals for foreground, background and compound picture output to the picture monitor. The very critical scenes used and the high-quality results obtained would not be properly reproduced by the PAL system with its restricted chrominance bandwidth so the results may not be thought to be applicable to PAL broadcast systems.

5. Conclusions

Colour Separation Overlay is an important production process which imposes stringent requirements on chrominance sampling frequency in a digital component video system. Experiments have shown that a chrominance bandwidth of at least 3 MHz (implying a sampling frequency of at least 6 MHz) is needed for satisfactory CSO. The luminance sampling frequency need not be constrained by CSO provided an additive overlay method is used as described in Section 2. Hence, it appears that a 13.5, 6.75, 6.75 MHz sampling standard for YUV signals is commensurate with good quality CSO.

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Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP